Single-Ion Optical Frequency Standards with ^{171}Yb$^+$: Measurements of Frequencies and Frequency Ratios

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The ^{171}Yb$^+$ ion possesses several transitions that are suitable as references in a frequency standard. All relevant wavelengths can be generated from diode lasers and the nuclear spin of $\hbar/2$ ensures a simple sublevel structure. Trapping of Yb$^+$ seems less effected by molecule formation than other ions. Storage times of several months are routinely observed in our room temperature vacuum system. The $^2S_{1/2}(F=0) \rightarrow {}^2D_{3/2}(F=2, m_F=0)$ electric quadrupole transition at 688 THz (436 nm) has been recommended as a secondary representation of the second in the optical frequency range. The electric octupole transition $^2S_{1/2} \rightarrow {}^2F_{7/2}$ at 642 THz (467 nm) with its nHz natural linewidth promises a reduced quantum-noise-limited instability for a single-ion optical clock, provided further progress can be made in laser linewidth narrowing. Because of the importance of relativistic contributions to the level energies, the ratio of these two transition frequencies is strongly dependent on the value of the fine structure constant α and measurements of this number against time should allow a sensitive search for temporal variation of α [1]. Such a measurement can be made with a femtosecond laser frequency comb, independent of the accuracy and stability limitations of microwave frequency standards.

We have designed and built a new variant of the endcap trap [2] in a compact vacuum system that provides improved control of the localisation of the ion, of electric and magnetic fields inside the trap and of the thermal environment. These measures shall allow to reduce the dominant contributions to the uncertainty budget of the 688 THz frequency standard, i.e. the quadrupole shift due to electric stray field gradients and the light shift due to thermal radiation [3]. Operation of the 688 THz frequency standard has been made autonomous to a large degree with computer control of all relevant laser parameters. This permits continuous averaging times of several days relative to a cesium fountain clock. For the development of the 642 THz frequency standard with its higher demands on reference laser power and frequency stability, we have obtained 467 nm radiation with an efficiency of more than 20% in second harmonic generation from 40 mW of infrared light produced in an extended cavity diode laser.

Using a fiber-laser based femtosecond frequency comb generator, we intend to perform repeated measurements of the frequency ratio between the 688 THz and 642 THz ^{171}Yb$^+$ frequency standards and of both absolute frequencies. For the quadrupole transition, a record of precise frequency measurements over a 6 years span has contributed to obtaining limits on temporal variations of fundamental constants [4,5,6]. Inclusion of the octupole transition will greatly enhance the sensitivity of these studies.

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